designfeature *By Bill Schweber, Technical Editor*

Drop by drop, "GREEN" DESIGN saves buckets of ac power

LOSING EVEN A FEW WATTS OF AC-LINE POWER HERE AND THERE ADDS UP. BY USING NEW TECHNIQUES IN LIGHTING, MOTOR CONTROL, AND STANDBY/CHARGER CIRCUITS, YOU CAN DRAMATICALLY CUT THIS AGGREGATE WASTE.

I f your application, such as a cell phone, global-positioning-system (GPS) receiver, or laptop PC, runs on batteries, you're painfully aware of every milli-watt of power that it requires. After all, you face a firm boundary on available energy: When that battery drains, your product is little more than an expensive paperweight.

However, if you always have that ac line available, your power constraints may seem to involve solely your ac/dc supply rating, thermal issues, and perhaps enclosure sizing. You're connected to what seems to be a supply of infinite capacity—that ac socket conveniently connected to a huge generator somewhere. You certainly don't worry about running out of power.

Yet a watt here and a watt there add up dramatically when you consider the aggregate number of similar losses in the millions of households in the United States, Europe, and Asia. It's a corollary to the law of large numbers: The product of a small number and a very big number is still a big number. For some applications, such as refrigerator motors and home lighting, power waste is not just a watt or so—it can be fairly substantial and costly in the long run.

Power waste is also your concern in other applications, such as the "keep-alive" or "soft-off" circuitry in TVs and VCRs, in which the user's on/off button shuts off most—but not all—of the circuitry. Further, those ubiquitous recharger "bricks" have quiescent consumption of 1 to 5W, even when they have no load to charge or when they just provide a keep-alive trickle of current rather than full charging current. In such cases, the cost to the end user is only a few dollars per year, but the cost to society as a whole in overall electric bills and the need for additional power sources is fairly large.

HIGH TECH TO THE LIGHT RESCUE

tackling the inefficiency of smaller values of power waste among an enormous number of users is now the target of modern electronics. This situation exists for two reasons. First, various environmental regulatory agencies in the United States and Europe now suggest or even demand energy-efficient designs. These agencies are setting goals (some voluntary, some mandatory) for reducing energy waste in common household products in which the end user may not see either the savings as significant or the cost-versus-benefit factors. (In contrast, commercial and industrial energy-saving applications often involve a much larger potential savings, a single site, and an easier-to-analyze cost/benefit situation.)

Consider household lighting, the most common household-electricity application. According to the 1993 Residential Energy Consumption Survey (RECS, www.eia.doe.gov/emeu/lighting/), the average US household consumed 940 kWhr of electricity for lighting. This figure is 9% of the household's total consumption. Note that this number is an average, and the per-household figure varies widely with the type of household (single family, mobile home, or apartment). The RECS Web site gives a more detailed breakdown of usage.

Although you use the incandescent bulb without a second thought in many household applications, its low efficiency provides lots of room for improvement (see **sidebar** "Old lamp designs still burn brightly"). No single alternative to the incandescent can replace it in all of its in-house applications, just as the basic incandescent bulb is not the answer to all lighting problems. By looking at how and why you use the bulb, however, you can find some effective alternatives in specific applications.

Consider the fluorescent approach. Fluorescents driven by a conventional ballast suffer from several shortcomings: The lamp tube is long (18 to 48 in.) for technical reasons; the ballast is inefficient, robbing about 20% of the power; the lamp sometimes has an annoying 50/60-Hz flicker that gets worse as the lamp ages; the ballast has a limited life; and the ballast generates an audible buzz at 50/60 Hz, which can range from barely to irritatingly audible, depending on the lamp-fixture construction, ballast age, and room resonances.

Luckily, an all-electronic ballast can overcome many of these problems at an acceptably low cost and can add other desirable features, such as end-of-life de-

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AT A GLANCE

▷ Power consumption of mundane household products—lamps, appliance motors, and wall adapters/rechargers—can add up to large amounts of wasted power.

▷ New IC-based technologies let you significantly cut consumption and realize other benefits in operating sophistication.

▷ These new designs are, in many cases, less expensive to build and operate than existing designs.

OLD LAMP DESIGNS STILL BURN BRIGHTLY

The filament incandescent bulb that Thomas Edison invented in 1879 is the dominant type of household light source. It provides 60% of the total light hours in the kitchen to 90% in the living room, family room, dining room, and bathrooms. Edison's original system used a dc supply, and today's systems almost universally use an ac supply. Today's bulbs are somewhat more efficient and have much longer lives than his, but little else has changed since the early days of incandescent illumination: We even use the same bulb base that Edison used in his bulbs.

The virtues of the filament incandescent bulb are many:

functional simplicity; ease of turn-on, turn-off, and dimming; low manufacturing cost; reasonable life; and near-sunlight-colored output. But, the low efficiency of this bulb—10 to 20 lm/W, or roughly 10%—is a severe shortcoming. This low efficiency means that you waste power, plus you have a bulb that gives off considerable heat, which the bulb must dissipate in its environment and which can start fires unless its fixture and shade have adequate design, installation, and maintenance.

Engineers developed the fluorescent lamp in the 1930s; it uses a very different principle from the venerable incandescent. This lamp produces elec-

trons in an arc between two cathodes. These electrons, in turn, hit the mercury vapor in the lamp and produce invisible UV light. To make the light visible, the inside of the lamp has a phosphor coating that fluoresces when the UV light hits it. By varying the phosphor recipe, lamp vendors can provide lamps that produce light from very white, to pinkish, to some other shades; many people find the very-white color harsh and artificial, which are drawbacks to using these lights in household settings.

With its output of approximately 50 to 80 lm/W of input power, the fluorescent is far more efficient than the incan-

descent lamp. Unfortunately, it is also larger and more complex internally and requires special drive and regulation circuitry ("ballast"), unlike the incandescent, which requires none. This ballast circuitry has two functions. First, it steps up the line voltage to a value that initiates (strikes) the arc between the electrodes. Second, it limits the lamp current in regular operation after the arc-striking phase. Traditionally, the ballast has been a relatively simple, passive, and inexpensive magnetic circuit, but it also has many operational shortcomings and limitations in matching the dynamics and aging of a load and of accommodating different loads.

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tection. Thus, for many home applications in which the conventional long fluorescent lamp is not a good physical or feature fit, you can replace the incandescent lamp with a compact fluorescent lamp (**Figure 1**). The ML4835 ballast controller from Micro Linear (www.microlinear.com) is a good example of how active electronic devices can provide better performance and desired features than well-established passive devices.

The $2.11 (1000), 20-pin ML4835 contains the control circuitry for electronic ballasts (**Figure 2**). A complete ballast also includes the ac/dc rectifier; the chopper circuit, which the ML4835 controls; and a filter network to minimize RFI. A designer can program this type of sophisticated control to match characteristics of particular bulbs, and this control uses extensive feedback to provide optimal performance during lamp-ignition and life-cycle stages. Fixed-parameter passive ballasts lack these capabilities. Operating frequency is in the tens of kilohertz. Addressing another weakness of conventional ballasts, the electronic-ballast controller has built-in power-factor

Figure 1

Using the Micro Linear ML4835 as a controller, you can build an efficient and versatile electronic ballast for compact fluorescent lamps, which can replace incandescent lamps in many consumer applications.

correction (see **sidebar** "Factor in power factor").

The controller IC has three operating frequencies—for start-up-element heating, arc striking, and dimming phases—and you can also set a preheat time to lengthen lamp life. All lamps eventually burn out; the IC senses this burnout by monitoring lamp current. If the current increases past a threshold, the IC shuts down lamp power. A temperature sensor monitors the ambient heat and shuts off

the lamp when the temperature exceeds 130 C, which may happen due to a wiring fault near the lamp.

These features alone justify using a compact fluorescent in place of a power-hungry incandescent in many situations. But a few of the features of a smart controller really show you the benefit of the electronic-ballast approach. Historically, one drawback of the fluorescent was that you couldn't dim it—something you can do relatively easily with the incandescent. But, with a smart controller and a variable-frequency drive, you can control brightness by increasing the frequency of the drive current to the lamp; the ballast filter attenuates this higher frequency drive signal, and the lamp dims without annoying flicker.

The smart controller also addresses the obvious question: Why should the lamp intensity be constant when a combination of variable daylight and artificial light illuminates the area of interest? You can use the output of a photosensor with the ML4835 to automatically dim the lamp as the ambient-light level increases, thus maintaining a roughly constant sum

FACTOR IN POWER FACTOR

In the ideal world, all children would be above-average, and all ac-main loads would be resistive—and stay so. But in the real world, neither is the case. Reactive loads cause the mains current and voltage to have a phase difference; the power factor is the cosine of this phase difference. Nonunity power factor is much more than an aesthetic concern. It is related to harmonic distortions of the sinusoidal signal of the power line, which in turn affects the real power (not the apparent power) that the utility must deliver. Low power factor also indicates harmonic currents, which can have many undesirable effects, such as unnecessary line and system heating, overvoltages due to line-resonance conditions, errors in line-metering equipment, interference with end-user equipment and systems, premature failure of motors and power

supplies, and random tripping of circuit breakers.

To negate the dangers of low power factor, standards such as EN 60666-2 (derived from IEC Harmonic Standard 555-2) define mandatory power factors for situations that your equipment must meet so that you can use or sell it in the countries of the European Union as well as in many other countries. Depending on circumstances, you may have to guarantee by design that your system yields a power factor of 0.9, 0.95, or even 0.99.

There are two ways to do power-factor correction (PFC). One is to add inductors and capacitors in the circuit to compensate for the load reactance. Alternatively, a ferroresonant input transformer or tuned input filter may work. These techniques, however, become cumbersome and bulky, as well as

costly, as power levels increase to more than a few watts; they are often awkward to implement even at lower power levels.

Again, IC technology offers a solution to a long-standing problem. With active PFC, the power unit dynamically corrects the power factor and pushes it toward unity. Boost, buck, and boost-buck topologies let you build PFC into the load; each successive technique among the three offers advantages over the previous one. In addition, vendors such as Cherry Semiconductor Corp (www.cherry-semi.com), Unitrode Integrated Circuits Corp (www.unitrode.com), Micro Linear Corp, and Motorola (www.mot.com) offer ICs that are designed for PFC functions, working with your power-supply circuitry. With the right design implementation, you should be able to achieve power factors

corrected to 0.98 or 0.99.

If you are doing motor control with a DSP you don't need an external PFC function: The DSP algorithms also implement PFC, as just another one of the many things the motor controller must take into account. Similarly, ASICs such as the ML4835 include PFC appropriate for the load that the IC aims to manage. **Reference A** is a good and readable overview of PFC and many energy-related issues, such as power-semiconductor devices, switching power supplies, and energy-efficient lighting.

REFERENCE
A. Kularatna, Nihal, *Power Electronics Design Handbook*, Newnes/Butterworth-Heinemann, 1998.

of natural- plus artificial-light levels. If you want to take your energy savings to another level, you can use the output of a motion detector in the room to dim the lamp when it detects no movement for several minutes.

Your power-saving opportunities are not limited to compact fluorescent lamps, either. The metal-halide lamp produces light by exciting a mixture of mercury and related halides, yielding about 80 lm/W of pleasant, sunlike illumination. Although the halide lamp's shape is similar to that of a standard incandescent lamp, the halide lamp requires a sophisticated drive circuit similar to that of the compact fluorescent. For home use, some vendors, such as the Microsun Technologies subsidiary of Advanced Lighting Technologies (www.microsun.com), offer complete table or floor-model lamps that contain the drive circuitry and bulbs. Although a 68W halide bulb costs about $20, it replaces five 75W incandescent bulbs and lasts about 10,000 hours, compared with the 1000-hour life of a typical incandescent bulb.

There's another light source that has near-ideal characteristics. LEDs have a long and successful history in many electronic projects, and the industry has increased LEDs' brightness by a factor of 10 from the early days of dim red versions. LEDs run cool—they are more than 90% efficient—and are easy to drive and dim from a simple current or current-limited voltage source. There are no RF issues with LED drives, and the diodes are mechanically rugged.

Complete assemblies of arrays with a large number of LEDs now have significant manufacturability and reliability history, along with requisite brightness for sunlight-visible outdoor applications. Most new cars now use red LEDs for the high-mounted brake light, and some use them for the main rear-brake lights as well. Traffic lights that previously used red, green, and yellow bulbs now use an array of approximately 80 extra-bright LEDs for the red signal, thus saving energy and reducing costly lamp-replacement labor.

All these features make LEDs sound like the ideal incandescent replacement. They would be, except that their brightness is just not sufficient for many home applications, and the color of the whitest LED array is not the kind of "white" that

Figure 2
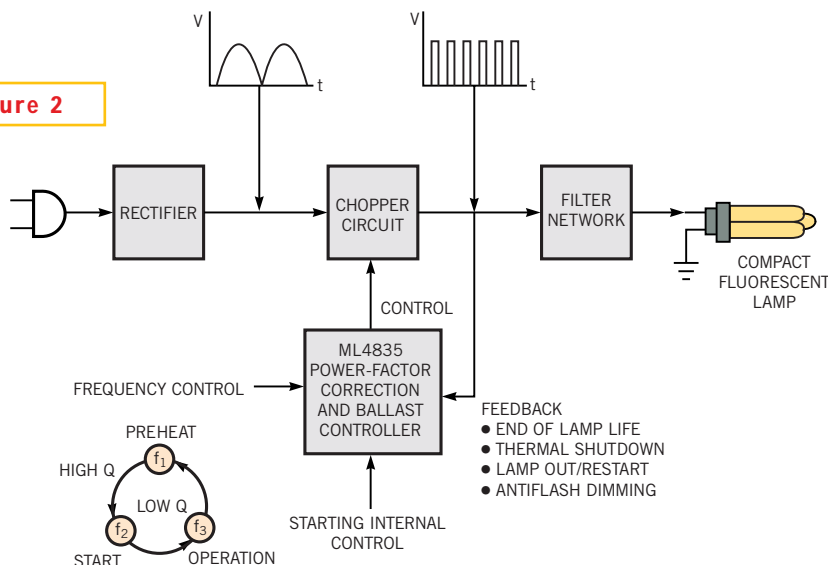
The compact-fluorescent-lamp controller must provide different functions in the three key cycles of the lamp's operation; it can also provide advanced end-of-life, thermal-shutdown, and dimming functions, all matched to the bulb type.

people normally want for reading and leisure. But a careful study of where people use incandescents shows that many find use in secondary applications, such as illuminating exit signs, in which these limitations are not a problem. In addition, many of these situations are those that get the greatest benefit from a high-efficiency source, because the lamp is on 24 hours a day.

You can effortlessly switch from a standard incandescent to an all-LED lamp using the A19 series of solid-state lamps from Ledtronics (www.ledtronics.com), for example. These lamps look like standard bulbs and have the common 25-mm

Figure 3

Go for maximum efficiency by using an all-LED replacement for the incandescent bulb, and you'll also get long life, cool running, and physical ruggedness.

Edison base, but their bulb envelopes are made of rugged polycarbonate (**Figure 3**). These units are available in colors including red, orange, amber, yellow, green, blue, and white (though they are not a direct substitute for a conventional white-light source). Although they consume just 0.7W, their light output is several hundred lumens, depending on color, thus making them suitable as replacements for 15 to 20W incandescent units. Prices range from $19 to $62 (100), also depending on color.

If you think that secondary applications such as exit signs are the only viable application for these LED incandescent replacements, you're wrong. Many situations use large arrays of low-power incandescent bulbs but in installations in which bulb replacement is a costly labor item in addition to the obvious energy-consumption cost. These LED bulbs have a life of at least 100,000 hours—100 times that of a typical incandescent lamp. Think about theme-park lighting, stage-accent lighting, casino and nightclub lighting, and those "chase lights" on movie-theater marquees and at amusement parks, and you'll see where you could replace thousands of incandescent bulbs with efficient, very-long-life LED equivalents. Doing so would save lots of money and minimize interruption despite LEDs' much higher initial cost and limited brightness.

MOTION NEED NOT CAUSE SICKNESS

electric motors come in an enormous variety of ac and dc units with many configurations and sub-species, but the staple of the fractional-horsepower electric-motor world is the ac induction motor. In sizes ranging from $\frac{1}{4}$ to $\frac{3}{4}$ hp

(1 hp=746W) and operating from a single-phase ac main, you use this motor in refrigerators, dishwashers, washing machines, air conditioners, and similar home appliances; this motor often performs reliably for 10 to 20 years. **Reference 1** gives detailed breakdowns on motor volumes by home application for each year from 1988 to 1998. The numbers are large and impressive: Vendors produced nearly 8 million standard refrigerators for use in the United States in 1997.

The primary virtue of the induction motor is that it has no brushes or similar contact parts that wear out: The rotor bearings are the only moving parts that might fail over time. If you use the induction motor within its rating and if you keep its temperature rise within specs so that the insulation doesn't break down, the induction motor performs faithfully.

The second virtue of the induction motor is that it requires no complex starter circuit, contributing to its low cost and long life. You can run the induction motor directly from the ac mains, and the starting circuitry consists of an auxiliary winding that it automatically switches out using a capacitive circuit that senses the change in motor rotor speed and current phase. It's not fancy, but it works well (see **sidebar** "Solve the problem using induction").

The induction motor's weaknesses are that it runs inefficiently and with low torque at speeds other than its rated values. It takes a lot of computational "horsepower"—a task well-suited for a DSP—to make the induction motor a more flexible and efficient source of mechanical power, because you need to control both the amplitude and the frequency of the waveform to the motor. An ac/dc rectifier, a smart controller that develops the needed sinelike waveforms, replaces the relatively direct connection between the mains and the motor, and a

dc/ac inverter drives the load with high voltages and currents.

DSP vendors have addressed this issue and have developed algorithms and techniques that are generally impractical with conventional passive or simpler electronic controls. Motor specialists have known of these advanced techniques for years, but they are impractical except for use with the largest motors, in which controller cost is a small portion of the overall system's initial and operating costs. Vendors have even extended their DSP-based controller systems to let you use fuzzy logic and neural nets for the control loop.

The basic technique of scalar control
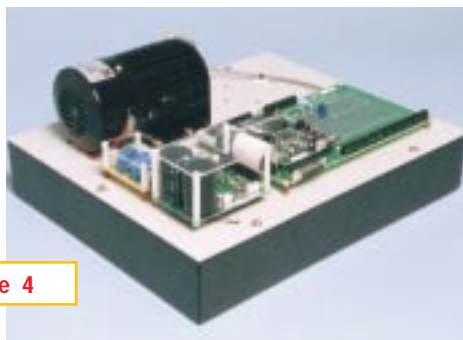
For advanced motor-control-algorithm development, use the real thing: The Motionpro DSP AC331 development system from Applied Microelectronics takes you from ac mains, through DSP, to a $\frac{1}{5}$-hp single-phase induction motor.

measures motor variables only by their magnitudes, with the controller feedback and control signals proportional to dc quantities. This "volts/hertz" method assumes that by varying the motor stator voltage in proportion to the applied line frequency, you keep the motor torque constant at a desired point on the speed-torque curve. The advantages of scalar control are its computational simplicity (a fast fixed-point DSP can usually do

this task) and small code-size requirements. However, this control does have drawbacks. The scalar method of control does a relatively poor job of responding to sudden load changes, and efficiency and performance suffer until the control loop and motor catch up with reality. You can improve the scalar-control method by adding precalculated tables based on known motor-performance models and using these tables to modify the control parameters in real time, but these steps add complexity and cost to the controller.

Alternatively, vector control offers much better potential performance but at the cost of complexity and DSP requirements. In this mode, the controller measures not only the signal magnitudes, but also their phases relative to each other. Then, it uses matrix math to perform the necessary calculations. Underlying these calculations are some fairly sophisticated analyses of motor-performance and -control techniques, such as field-oriented control. **Reference 2** has an excellent and brief discussion of vector-control issues and techniques.

One other problem with scalar and vector control for induction motors is that, as closed-loop control systems, they require a feedback sensor on the motor shaft to report shaft position or speed. This feedback sensor adds cost to the overall design, affects long-term reliability, and introduces difficult mechanical constraints, none of which are desirable in a home-appliance application.

An alternative to sensor-based closed-loop control uses principles of modeling and estimation to derive the closed-loop information. In the *model-reference-adaptive* system, the controller compares actual motor current and voltage measurements with what it would expect to see, based on a complex model of the motor system. This motor model is not static, either, and must change to correspond to phases of the motor's operation, so the algorithm can become quite complicated. With the *state-space-estimator* approach, both the model and the motor receive the same commands. The algorithm compares the error in the value of an easily measured variable, such as stator current, in the model and in the real motor to provide corrective direc-

tion. A more advanced state-space estimator uses Kalman filtering to adjust estimation parameters based on implied random errors in the measurements. All of these sensorless techniques require sophisticated algorithms, understanding of the real world of motors, and fast floating-point DSPs.

Both Analog Devices (www.analog.com) and Texas Instruments (www.ti.com) are heavily involved in the DSP motor-control effort, and both recognize that consumer-level induction-motor control must cost $20 to $30 to be acceptable to the appliance market. The companies also know that, like so many

real-world functions, there are many operating subtleties and exceptions that the motor industry has been dealing with for many years and that may not fit into any idealized theory.

To further support these DSP motor-control efforts, both vendors (as well as others) have produced multichannel

SOLVE THE PROBLEM USING INDUCTION

The ac induction motor's virtues are simplicity, reliability, and ease of operation. (All of these virtues became apparent when Nikola Tesla invented it in 1888; the first dc motors appeared in the 1830s). These features make the ac induction motor a good choice for

fractional-horsepower consumer applications in which the motor must operate for many years with no attention from its owner, albeit not with 100% duty cycle.

But these virtues come with performance limitations. The efficiency of the motor is

typically 60 to 80% when you use it at or near the rated synchronous speed. Maximum efficiency for a given motor is a function of the amount and quality of the steel in the rotor laminations, the gauge of the winding conductors, and the size of the air gap between the stator and the rotor; in general, higher efficiency designs cost more in material and assembly precision.

The ac-mains frequency and the physical-winding configuration of the motor establish the motor's synchronous speed. Reducing the applied voltage reduces revolutions per minute but with a sharp falloff in torque and efficiency (**Figure A**). Thus, you almost always use the induction motor at one speed. If you need variable speed, you need to use pulleys and belts for power transmission, but these extras are costly and unreliable for many applications.

Although the induction motor is simple, its operation from 0 rpm to rated speed involves several time regions and changes in the current it draws from the line (**Figure B**). The equivalent mathematical model of the motor changes dramatically from region to region as well. Any advanced algorithm that manages the motor must accommodate the modes of operation and time lines involved in each phase. Similarly, the processor-controlled power drivers must accommodate the reality of motors and inductive circuits. The transient inrush current of the 0 rpm, locked-rotor motor is typically six times the nominal rated running current at maximum revolutions per minute, for example. If you want to see the intense level of quantitative analysis that exists for all classes of motors, check out **Reference A**.

Figure A
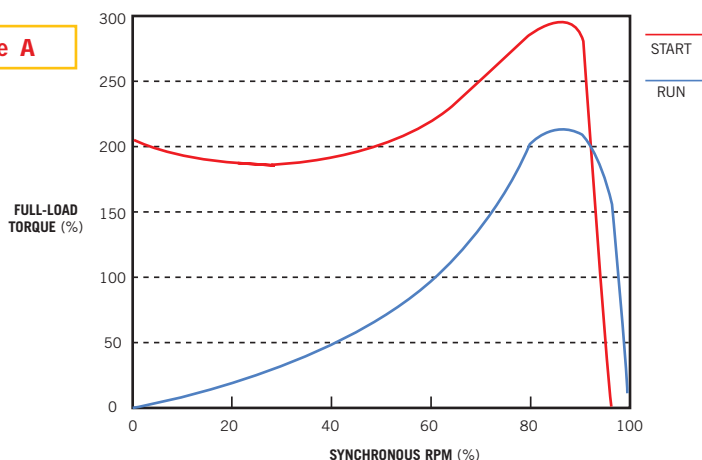
The torque-versus-speed curve for a typical single-phase induction motor shows the rapid falloff in torque outside the 80 to 90% synchronous-speed band (adapted from Reference A).

Figure B
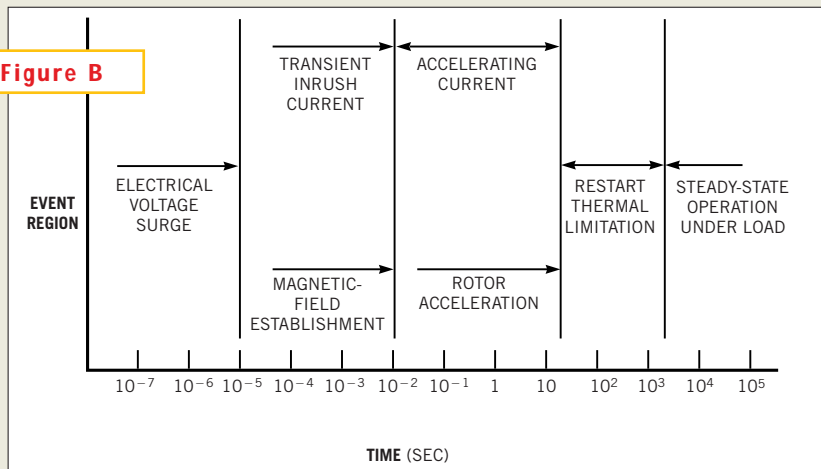
Induction motors go through several critical phases of varying lengths from start-up through steady-state operation (adapted from Reference A).

REFERENCE
A. Englemann, Richard H, and William H Middendorf (editors), *Handbook of Electric Motors*, Marcel Dekker, 1995.

ADCs for simultaneous, synchronized sampling of motor signals. Although these converters are slow by instrumentation and RF standards—at just tens of kilosamples/second versus megasample/second rates—they have the resolution and parallel converter-channel operation that multisignal measurement requires.

Texas Instruments offers the TMS-320C24x family with a register set and I/O that is optimized for such closed-loop-control functions. The company has also produced some detailed application notes. **Reference 3** offers motor-control tutorials followed by practical discussions and appropriate software. Analog Devices closely worked with Applied Microelectronics (www.appliedmicro.ns.ca), which now offers the Motionpro DSP AC331 development kit. This kit provides all the hardware and much of the software needed for field-oriented control of an induction motor (**Figure 4**). The kit also includes a $^1/_5$-hp induction motor, an ADMC331 motion-control DSP, an integrated power stage, a current-sense board, a tachometer, DSP code, and PC-based development tools. Note that a DSP is not the only way to solve the motor-control problem. Start-up Anacon Systems (www.anaconsystems.com) uses an 8-bit RISC core supplemented by specialized peripheral functions and multiplier blocks to produce a motor-controller ASIC.

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2. Moynihan, Finbarr, "Vector control comes to home-appliance motors," *Machine Design*, June 4, 1998, pg 67.

3. "Enhanced control of an alternating current motor using fuzzy logic and a TMS320 DSP (SPRA057)," 1996; "Digital signal processing solution for ac induction motor (BPRA043)," 1996; and "AC induction motor control using constant V/Hz principle and space vector PWM technique with TMS320C240," April 1998; Texas Instruments, www.ti.com.

DRY UP AVOIDABLE LEAKAGE

If ever there was a case of "a few pennies here, a few pennies there; soon it adds up to real money," then ac wall adapters/rechargers used by cell phones, answering machines, portable CD players, rechargeable tools, and cordless phones is it.

There is also the less visible circuitry that is always "on": Virtually all advanced appliances, such as microwave ovens, TVs, VCRs, cable-TV boxes, and PCs, have keep-alive circuitry that powers critical functions within, even when the device is supposedly "off." (Note: Environmental advisors and some regulatory agencies have chosen to call this waste "leakage"—an unfortunate choice because engineers use the word to identify any inadvertent flow of current in unintended paths, such as through a chassis to ground or across RF terminals. But leakage has a certain public-relations ring to it, so engineers will apparently just have to live with it.)

The average wall adapter or keep-alive circuit consumes 1 to 5W, even under no-load conditions. The inexpensive design of these units is such that their quiescent current, whether under no-load or under trickle-charge conditions, is relatively high compared with their full-load current. (This situation is due mainly to their cheap transformers with high core losses.) Appliances in standby mode dissipate about as much power as wall adapters. One detailed study finds that the typical American home has *at least* 10 of these energy-wasting circuits, adding up to 50 to 100W of constant consumption (**Reference 1** of this section, pg 99). Figures from this study and other sources for Japan and Germany have similar results.

Although this isn't a lot of power—it's comparable to a single light bulb left on all the time—it does add up. Extrapolating to the entire United States, the study estimates 45 TWhr (45×10^{12} Whr) of waste, costing $3.5 billion to $5.4 billion annually (assuming that electricity costs 7 to 12 cents per kilowatt hour). The cost is even higher if the incremental con-

Figure 5
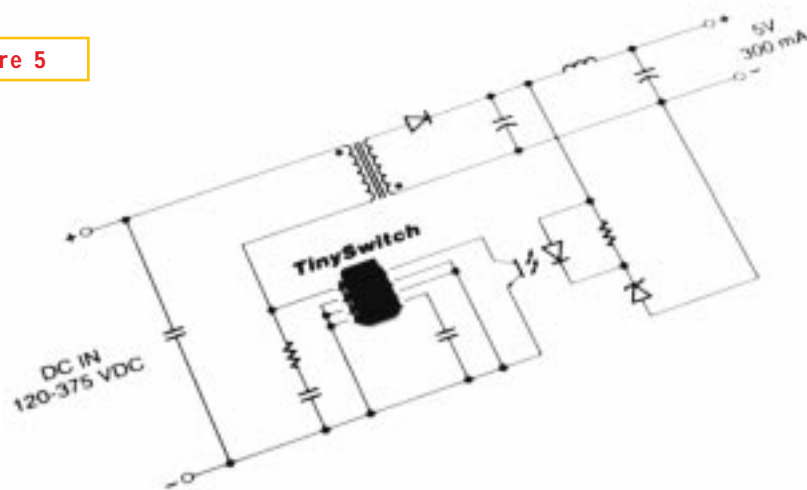
Using the Tinyswitch from Power Integrations as the core, you can build a wall adapter/recharger that is smaller, lighter, and far more efficient than traditional designs, especially in the common but highly wasteful no- or low-load modes.

sumption forces utilities to add new generating or distribution capacity. (One note of caution: Agencies and bodies that have a predefined agenda often do these studies; thus, they tend to use worst-case numbers for the current situation and then compare them with best-case future numbers that you can expect if the industry adopts their proposed solution.)

Responding to this large sum of many small leakage losses, the Energy Star program from the Environmental Protection Agency encourages manufacturers to build TVs and VCRs that consume less than 3 and 4W, respectively, in standby mode. The comparable program in Germany, the "Blue Angel" Eco Norm, demands less than 1W of consumption in standby mode. Fortunately, meeting these standards is not going to be too difficult. First, the standby circuitry that your design needs to keep alive is dropping in power requirements with each generation of product, so you can design smaller power-source circuitry.

Second, new line-powered power-supply topologies are also making these efficiency goals realistic. For example, the TEA156x series from Philips Semiconductors (www.semiconductors.philips.com) uses a burst-mode control technique to cut dissipation to less than 1W in standby mode; this technique also allows the IC to support supplies ranging from a few watts to as high as 125W, depending on family member. The 78-cent to $1.58 (OEM) device uses a flyback topology with a fixed switching frequency and constant primary-peak-current control. Using similar techniques and topologies, the 90-cent (10,000) VIPer20 from STMicroelectronics (www.st.com) provides output capability to 20W with a 180 to 270V-ac supply or 10W from a universal 85 to 270V-ac supply. Its 620V/0.5A power MOSFETs operate without any RC snubbers, saving additional cost, and you can also get other versions that have higher output-power capability.

The other advantage of these advanced off-the-line supplies is that they operate at higher frequencies, typically 100 to 200 kHz, compared with their less-efficient predecessors. Thus, you can replace the relatively large and costly magnetic elements, such as inductors and transformers, with smaller, cheaper, and lighter versions.

The traditional wall-adapter/recharg-

er design uses a linear supply, resulting in 40 to 45% typical efficiency plus large no-load dissipation. These supplies are relatively small, often delivering no more than a few watts maximum to their load; ironically, the supply's no-load consumption sometimes exceeds the full-load current that the supply delivers.

But these inexpensive-to-build, expensive-to-operate linear bricks are seeing competition from advanced technologies as well. With parts from the Tinyswitch family from Power Integrations Inc (www.powerint.com), for example, you can use a single 75- to 81-cent (10,000) (depending on rating) IC as a core to implement a novel switching-architecture design. The resulting supply features 70 to 75% full-load efficiency and 100-mW no-load consumption (a small fraction of a linear supply) and allows you to use fewer and smaller components (**Figure 5**).

Although operating efficiency is nice, the extremely cost-sensitive application of these adapter/recharger units does not tolerate products that have a higher initial cost even if they yield long-term energy savings. In this case, though, you don't have to worry. The requisite parts cost less, and the feedback loop between the isolated load side and the primary ac-line side is a simple optocoupler, so you can use a basic two-winding transformer with just a few turns on each winding. As an additional benefit, the weight and volume of a brick based on this technology are approximately one-fourth those of a conventional linear brick—a considerable savings. □

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Acknowledgment

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